

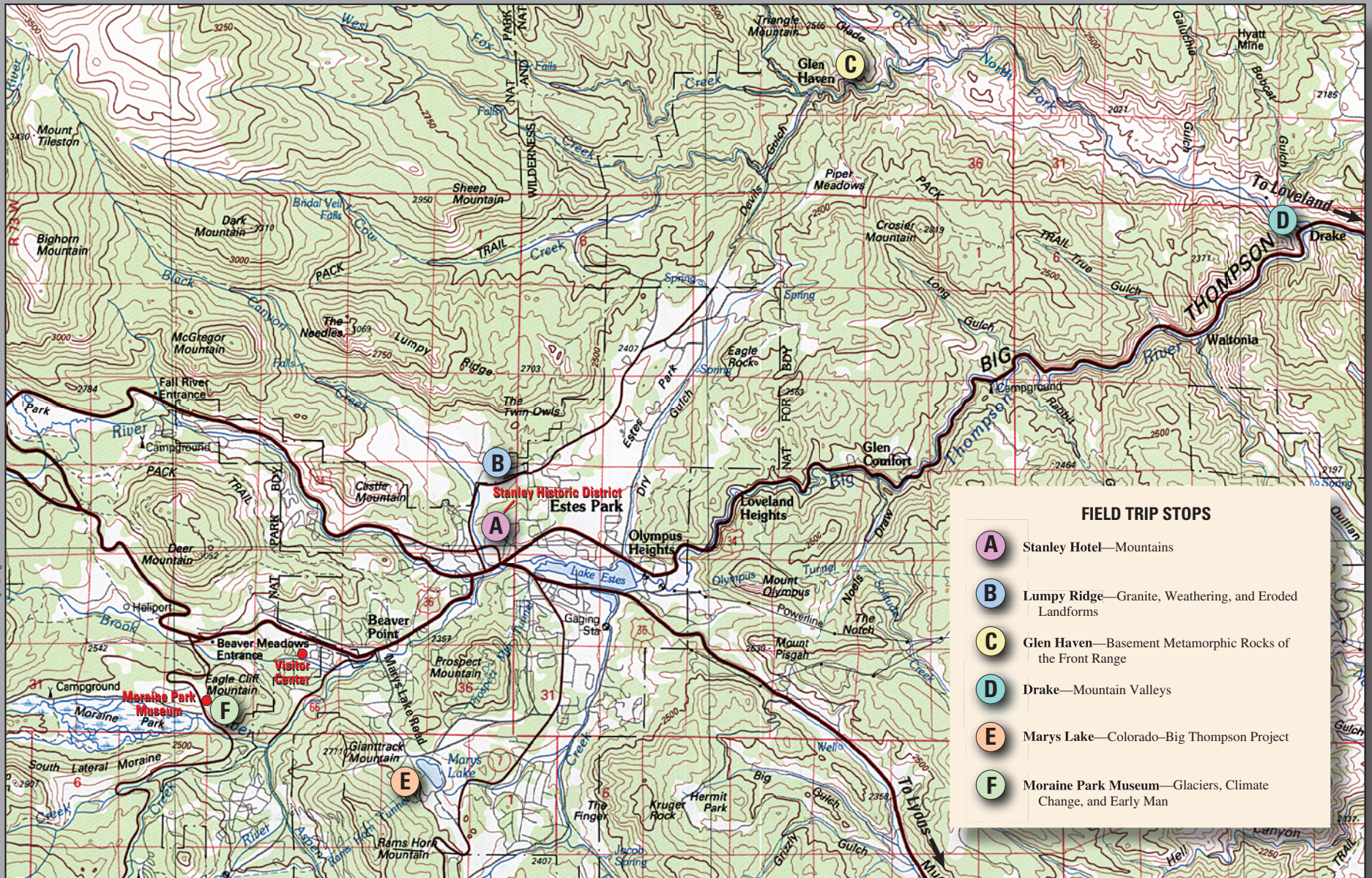


Guide to Roadside Geologic Exploration Around Estes Park, Colorado

By James C. Cole, U.S. Geological Survey

105°30'

40°
22'
30"



FIELD TRIP STOPS

- A** Stanley Hotel—Mountains
- B** Lumpy Ridge—Granite, Weathering, and Eroded Landforms
- C** Glen Haven—Basement Metamorphic Rocks of the Front Range
- D** Drake—Mountain Valleys
- E** Marys Lake—Colorado—Big Thompson Project
- F** Moraine Park Museum—Glaciers, Climate Change, and Early Man



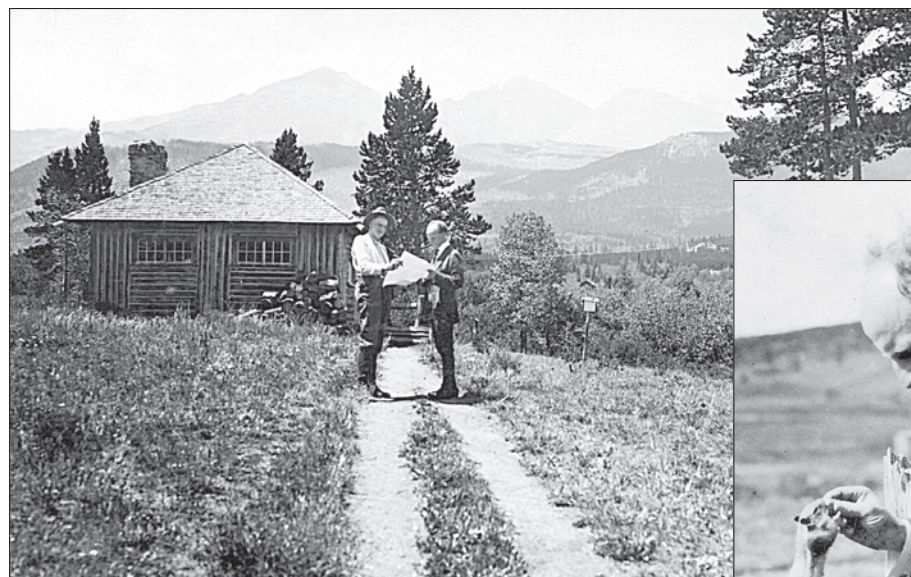
Introduction

The fact that you are reading this illustrated field guide probably means you are curious about your natural surroundings. More than likely, you look across the landscapes and notice similarities with and differences from other places you have traveled. If you like solving puzzles or studying history or archeology, then you already have many of the necessary tools to figure out some of the geologic riddles of the Estes Park region.

The modern science of geology is founded on the presumption that Earth processes observed today (for example, water and wind erosion, sedimentation, earthquakes, and volcanic eruptions) are similar to processes that have acted throughout geologic time. This is called the Principle of Uniformitarianism. Earth scientists have accumulated lots of evidence that this presumption is reasonable. However, this does not mean that processes have always operated at the same rates, or that the Earth has always looked as it does today.

The basic concepts of geology were discovered in the outdoors by people like Enos Mills who were curious about the rocks they saw, about the relationships of one rock mass to another, about minerals and fossils contained in those rocks, and about the actions of water, wind, and ice on shaping the landscape. With an active imagination and awareness of Earth processes you see every day, you too can make logical interpretations about features you see in the rocks—those signs of events that transpired long ago.

This guide describes six localities in and around Estes Park. The description of each locale is self-contained, so you need not explore the localities in any particular order. You can pick and choose among them to devise your own journey of geologic discovery based on your interests, your available time, weather conditions, and your starting point and ultimate destination.



(Far left) Naturalist Enos A. Mills (1870–1922), who was instrumental in promoting the establishment of Rocky Mountain National Park, is shown at his cabin beneath Longs Peak with USGS photographer W.T. Lee (with hat) in 1916. Mills took more than 15,000 photographs during his exploration of the Rocky Mountains and used them to promote outdoor education. Image courtesy of U.S. Geological Survey Photographic Library.

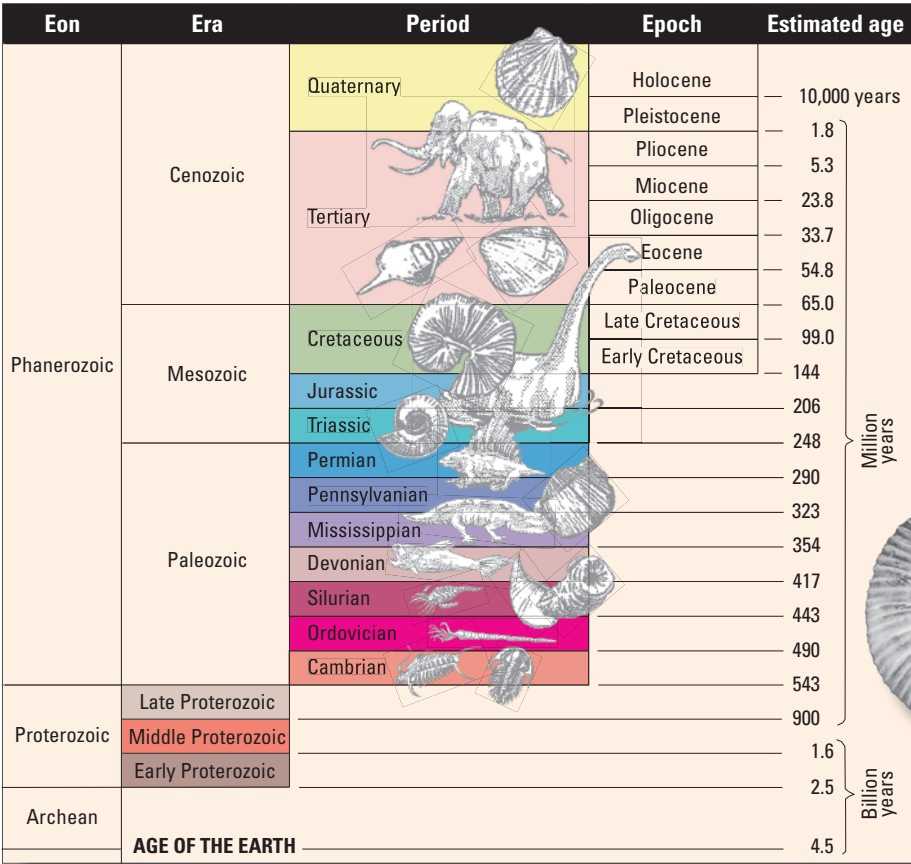
(Left) Enos A. Mills and golden-mantled ground squirrel outside Mills' Longs Peak Inn, 1916. Image courtesy of U.S. Geological Survey Photographic Library.

◀ **(Facing page)** Topographic map of the Estes Park area showing locations of stops described in this guide (contour interval is 50 meters, about 165 feet). Modified from U.S. Geological Survey Estes Park quadrangle.

Introduction

3 Introduction

Geologic Time Chart



Geologic Age of the Earth Expressed as a Single Calendar Year

(Adapted from Raup, 1996)

Day 1
Separation of the Earth from Solar System nebula
About 4.5 billion years ago



Geologic Time

Our perception of time is cultural, and it is natural that we think of time on a scale of days, years, and generations. However, we must think of time and change at much slower tempos to comprehend changes over geologic time. For example, our daily and seasonal weather changes are not very important geologically, because they are statistically “normal” when averaged over decades and centuries. In contrast, significant geologic change is recorded by the last major glacial advance from about 18,000 to 12,000 years ago—a period of about 6,000 years at the end of the Ice Age. But even that time is a mere blink over the span of geologic time. Cosmologists calculate that the Earth separated from the gas nebula of our early Solar System about 4.5 billion years ago. That’s 4,500,000,000 years ago. The initial uplift of the modern Rocky Mountains began about 70 million years ago—a very long time ago in human terms, but only about 1.5 percent of the

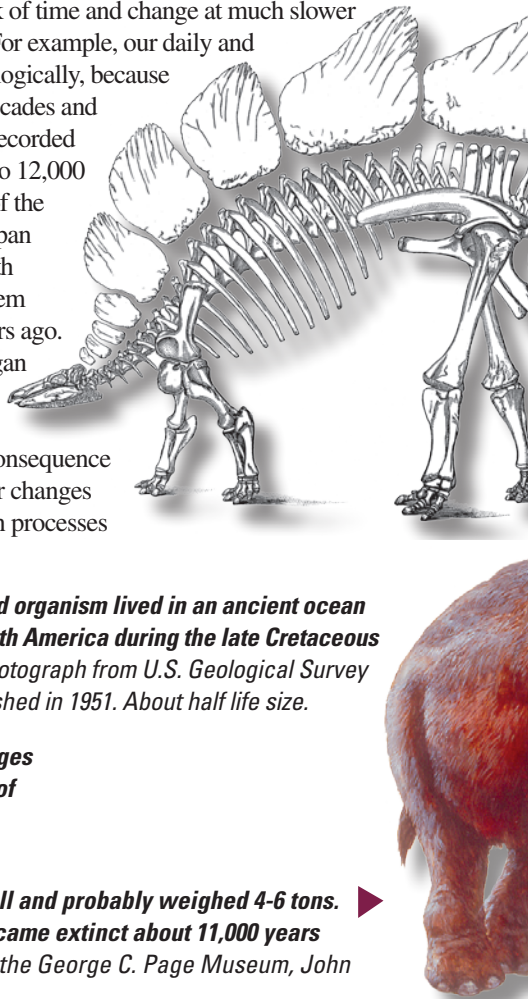
age of the Earth. The important consequence of vast geologic time is that major changes can occur even though most Earth processes take place at very slow rates.



◀ **Fossil ammonite.** This shelled organism lived in an ancient ocean that once covered part of North America during the late Cretaceous (99–65 million years ago). Photograph from U.S. Geological Survey Professional Paper 239, published in 1951. About half life size.

◀ **Geologic time chart showing names and age-ranges of major geologic periods and first appearances of significant animal groups.**

The American mastodon was as much as 8-9 feet tall and probably weighed 4-6 tons. It lived in North America during the Ice Age and became extinct about 11,000 years ago, during the late Pleistocene. Image courtesy of the George C. Page Museum, John Dawson, artist.

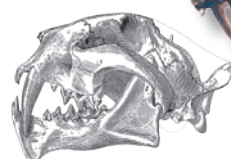


Safety Notes

This field guide describes sites that are easily accessible from two-lane roads around Estes Park, Colorado. All are public streets and highways, subject to the normal variations in traffic, deterioration, maintenance work, and driveability under variable weather conditions. The stops described in this guide were selected in part because all have adequate space to park safely off the roadway. Please remain aware of roadway conditions, and exercise good judgment when near the traffic lanes. Some of the stops are at road cuts or hill slopes where risks of loose or falling rock should be kept in mind.

Restoration of Stegosaurus skeleton by O.C. Marsh. This dinosaur lived sometime during the Jurassic Period, about 206–144 million years ago.

Stegosaurus is the official State fossil of Colorado. Engraving from Sixteenth Annual Report of the United States Geological Survey, published in 1886.



The saber-toothed cat was a large predator (similar in size to modern African lions, about 300–500 pounds) that lived in North America and became extinct about 11,000 years ago. Image courtesy of the George C. Page Museum, John Dawson, artist. Engraving of saber-toothed cat skull from American Museum Journal 1, published in 1901.

Restoration of American mastodon skeleton. Engraving from U.S. Geological Survey Monograph 27, published in 1896.

Day 227–Day 250

Formation of metamorphic rocks and intrusion of granites in the Colorado Front Range 1.7–1.4 billion years ago

Day 365

11:59:58 p.m. (last 2 seconds) Industrial Revolution 300 years ago

11:59:46 p.m. Birth of Christ 2,000 years ago

11:58 p.m. Last Ice Age 20,000 years ago

Day 364

"Young" uplift of Rocky Mountains Begins about 15 million years ago

Day 358

Laramide orogeny Begins about 70 million years ago

Day 346–Day 361

Age of the dinosaurs 240–65 million years ago

ly

August

September

October

November

December

Introduction

5 Stop A—Stanley Hotel

Stop A Stanley Hotel (Mountains)

Directions: From the junction of Highway 34 and Highway 36 at the east end of Estes Park, proceed north about 0.2 mile to the entrance to the Stanley Historic District (Steamer Drive). Turn right on Steamer Drive and continue 150 feet to “T” intersection. Turn left (Service Entrance) and park immediately in the informal gravel parking area on the left.

The view west over the town of Estes Park shows the jagged crest of the Continental Divide where it is crossed by Trail Ridge Road. The highest point on the road is just over 12,000 feet above sea level, and most of the peaks along the Divide are over 13,000 feet altitude. View to the south shows the dramatic summit of Longs Peak (14,255 feet altitude), the highest peak in the Front Range and the highest peak north of Interstate 70.

The rocks that make up Longs Peak and the other high summits in Rocky Mountain National Park are ancient gneisses, schists, and granites that originally formed far below the Earth’s surface. Experimental laboratory evidence for rocks subjected to high temperatures and pressures suggests that these kinds of rocks were buried about 12 miles deep when they crystallized more than a billion years ago.

Younger sedimentary deposits in this region, called the Pierre Shale, contain marine fossils that were deposited in an ancient ocean basin. The Pierre Shale is now found at high altitudes in the western part of Rocky Mountain National Park (Never Summer Mountains at 13,000 feet) and beneath the High Plains (at 5,500 feet). The Pierre Shale indicates most of northern and eastern Colorado lay somewhat below sea level as recently as 70 million years ago.

Right away, we face several questions. How did the ancient metamorphic rocks end up here, nearly 15 miles higher than where they formed? What caused the seas to retreat and raise the Pierre Shale more than 2 miles high? When did these mountains form? And perhaps the biggest question of all: Why are there mountains, anyway?

Almost every Earth process we observe around us works to bring down the mountains. Rain, melting snow, and streams carry sediment down from the heights toward the lowlands. Rockfalls and landslides move debris down toward the valleys. Wind carries silt and sand away from the heights. Glaciers flow down alpine valleys and carry away rubble from the valley sides and floors. Gravity and weathering operate day-in and day-out, year-in and year-out, over centuries and millennia, relentlessly eroding the peaks.

Longs Peak (14,259 feet) is the highest and most identifiable peak in Rocky Mountain National Park. Its broad, flat summit may be an uplifted remnant of an old Eocene erosion surface.

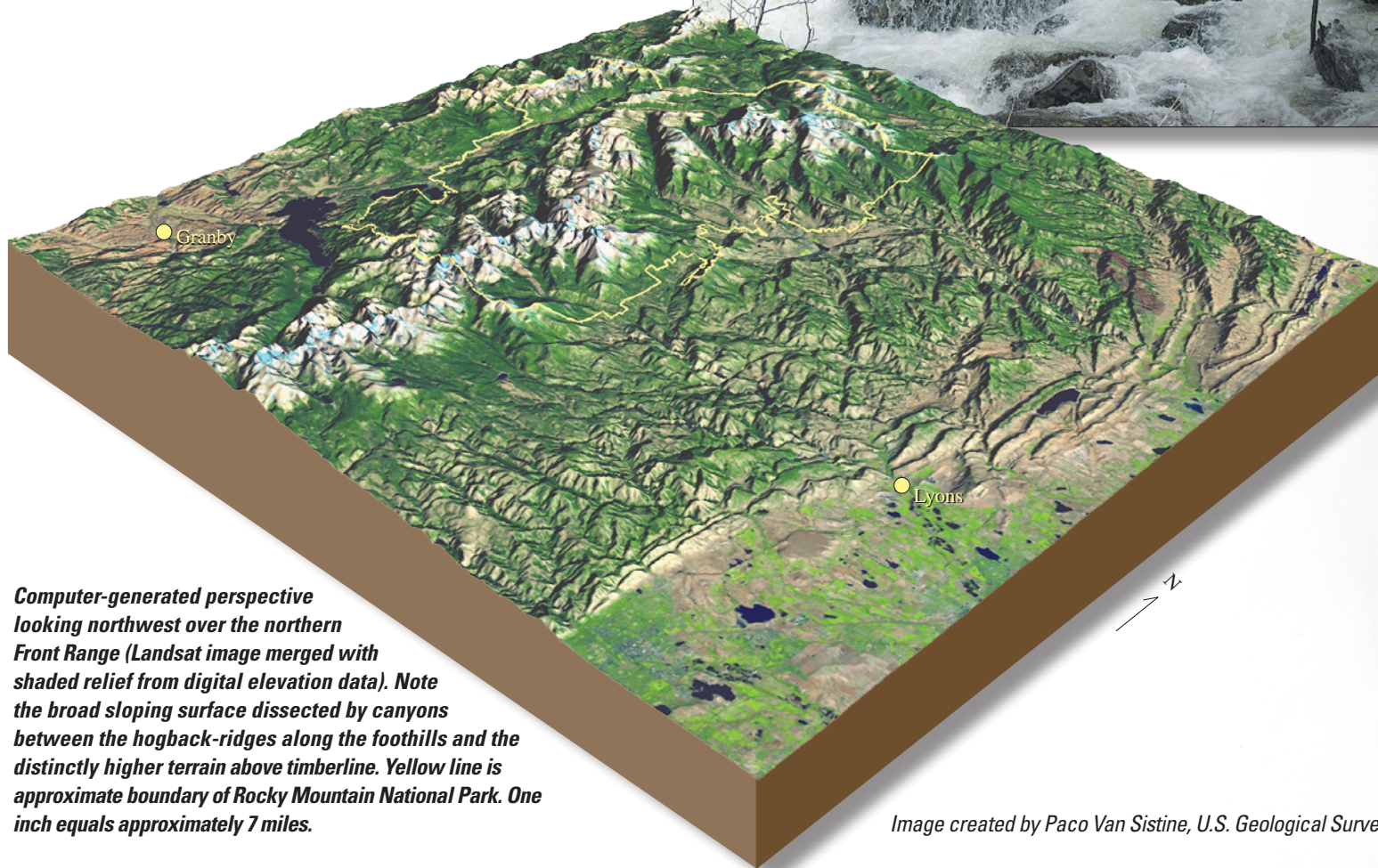


How fast does erosion happen? Suppose that all these processes had the effect of reducing the mountain altitudes by only one millimeter (about one-twenty-fifth of an inch) per year. That doesn't sound like much, but over geologic time it would reduce the mountain heights by about 10 centimeters (4 inches) in a century, one meter (39 inches) in a millennium, and 1,000 meters (3,300 feet, or nearly 0.6 mile) over a million years.

These mountains tell us that erosion is not the only process at work—UPLIFT also shapes the landscape. However, uplift is generally hard to observe on the human time scale because it happens slowly and it affects very broad areas.



Running water constantly wears away the landscape and erodes the mountain heights.

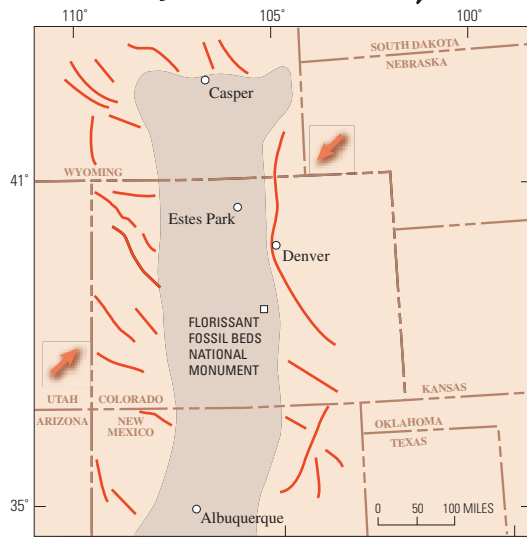


Computer-generated perspective looking northwest over the northern Front Range (Landsat image merged with shaded relief from digital elevation data). Note the broad sloping surface dissected by canyons between the hogback-ridges along the foothills and the distinctly higher terrain above timberline. Yellow line is approximate boundary of Rocky Mountain National Park. One inch equals approximately 7 miles.

Image created by Paco Van Sistine, U.S. Geological Survey.

Stanley Hotel

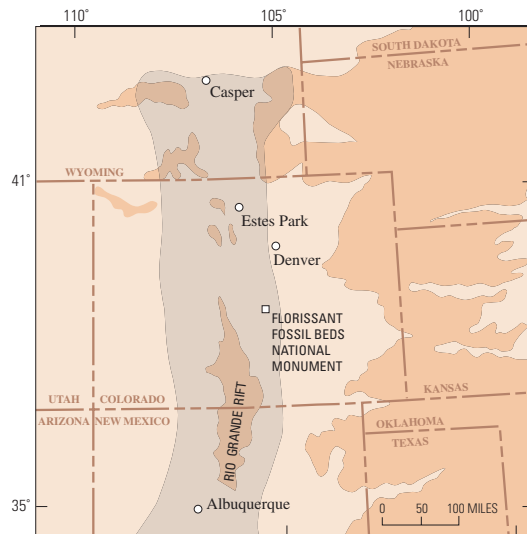
7 Stop A—Stanley Hotel



EXPLANATION

- Area of younger uplift during the Miocene and Pliocene
- Trends of Laramide block uplifts and crumpled folds
- Direction of compression

Sketch map showing mostly northwest-southeast trends of block uplifts and crumpled folds that formed during the Laramide orogeny (70 to about 50 million years ago) during initial uplift of the Rocky Mountains. Adapted from Eaton (1986).



EXPLANATION

- Sediments eroded from younger (Miocene-Pliocene) uplift of southern Rocky Mountains (15–5 million years ago)
- Area of younger uplift during the Miocene and Pliocene

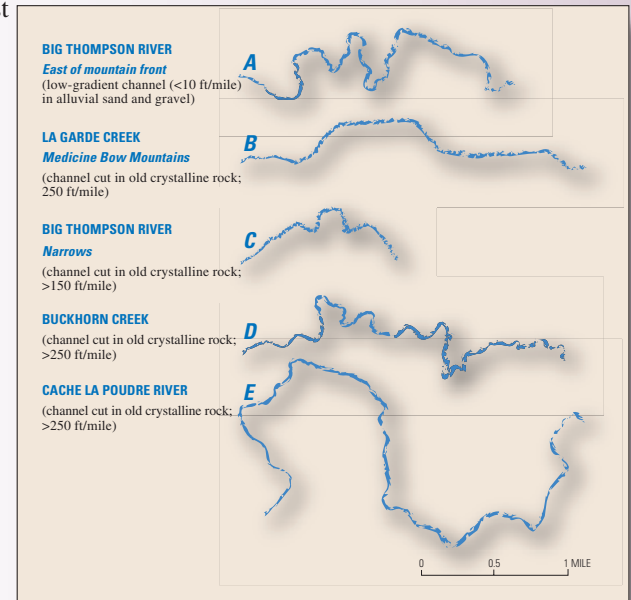
Sketch map showing the north-south trend of the broad uplifted arch that defines the modern South-ern Rocky Mountains that have risen in the last 15 million years. Sediments eroded from the rising Rockies were laid down in deposits that form broad, flanking slopes east of the mountain front, especially on the High Plains to the east. Adapted from Eaton (1986).

Geologists have learned that the Front Range uplift happened in two main phases. The first uplift took place at the end of the “age of dinosaurs” about 70 million years ago. The great inland sea (where the Pierre Shale was deposited) slowly withdrew to the Gulf of Mexico as the land rose by faulting and buckling in a long event called the “Laramide orogeny” (“oro-” = mountain; “-gene” = birth). Lakebeds preserved at Florissant Fossil Beds National Monument (about 100 miles south of Estes Park) were deposited in the uplifted and eroded terrain about 35 million years ago. They contain leaves and seeds of plants that probably grew at altitudes no greater than 3,000 feet above sea level. Such evidence suggests these Laramide-age mountains were probably never very tall.

Looking eastward over Lake Estes, you see no really high peaks east of Twin Sisters Mountain (the high ridge just left of Longs Peak). The gentler topography to the east reflects a broad upland surface that probably formed as the Laramide-age mountains were eroded and beveled at about the time the Florissant lakes existed. The streams and rivers active at that time had sinuous paths because they flowed on gently sloping surfaces. When the second uplift began about 15 million years ago, these sinuous river courses cut straight down into the solid crystalline rocks in the core of the range because they could not cut laterally against the hard rock. Most streams that drain the Front Range show these entrenched, meandering canyons that formed during the younger uplift.

This second uplift of the Front Range has the form of a broad, regional arch that can be traced from near El Paso, Texas, to Casper, Wyoming. It has a north-south trend that is different from the structural alignment of the earlier uplifts that formed in the Laramide orogeny. The central part of this arch was uplifted even more about 7–4 million years ago, which is why Colorado has so many peaks taller than 14,000 feet. Increased uplift led to increased erosion of the uplifted area, with deposition of sediments on the broad, flanking slopes east of the mountain front. The rate of uplift has been slower than erosion in the last 4 million years, and so the North and South Platte Rivers and their tributaries have steadily eroded broad valleys into these sediments.

Comparison of river courses (traced from maps at the same scale). Rivers that have low gradients (A) typically meander; medium- to high-gradient rivers (B) tend to have straighter courses. High-gradient rivers in the Front Range (C, D, E) show meandering valleys cut deep into hard rock, indicating they originally formed on a more gently sloping surface.



Stop B Lumpy Ridge (Granite, Weathering, and Eroded Landforms)

Directions: Exit Stanley Historic District and turn right onto Highway 34. Proceed west about 0.1 mile to MacGregor Avenue (note signs for Glen Haven and Devils Gulch Road). Make a right-hand turn onto MacGregor Avenue (toward Glen Haven) and proceed about 0.7 mile to the gateway to the historic 1873 MacGregor Ranch. Park on the right, just after the right-hand turn.



Bald granite knobs and irregular, fanciful forms stand out on Lumpy Ridge north of Estes Park.

The mountain landform north of this location is appropriately named *Lumpy Ridge* for its numerous domes, irregular rounded spires, and bare-rock exposures. But why is Lumpy Ridge so . . . lumpy?

Rocks appear hard, tough, and ageless. By contrast, living things seem fragile and seasonal. If you run your hand gently over a rock outcrop, some mineral grains will crumble away while others are held fast. This is a small-scale demonstration of how rocks slowly change over time. The processes of weathering decompose “hard” rocks, break them down, and prepare them to be eroded more easily by water, wind, and gravity.

Weathering involves several mechanisms. Chemical breakdown weakens mineral grains and the cement that binds them together. Physical (mechanical) weathering happens when the rock is changed by wind or rain or by the freezing and thawing of ice. Rocks are also attacked and changed by plants, particularly lichens that extract mineral nutrients from the rocks and secrete chemical residues that further attack the rock surface. Slowly, over thousands and millions of years, these processes change the form of exposed rock and produce the shapes like those on Lumpy Ridge.

Granite, the tan-brown rock that makes up most of Lumpy Ridge, is very uniform in composition and texture because it originally formed from molten rock (magma) deep within the Earth’s crust. What happens when a very uniform rock weathers? Consider the way a block of uniform ice melts. Block faces melt at the slowest rate because they are exposed to warm air on just one side. Edges melt a little faster because they are “attacked” from two sides. The corners melt fastest because warm air surrounds them on three sides. By melting or weathering, angular blocks are transformed to smoother, rounded, lumpier shapes.

Weathering and exfoliation on Lumpy Ridge have produced landforms with evocative shapes. Can you identify those known locally as the *Twin Owls*, *The Needles*, *Observatory Dome*, and *The Pear*?

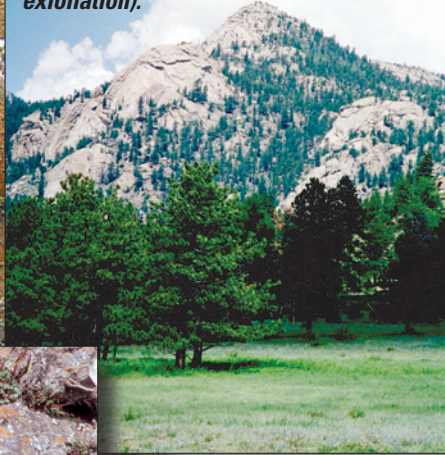
Lumpy Ridge

9 Stop B—Lumpy Ridge



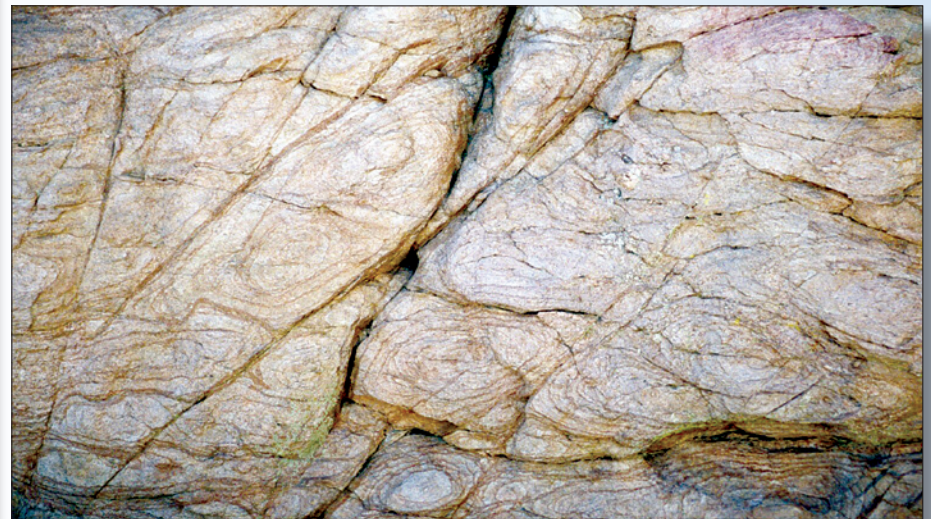
Brightly colored lichens are communities of algae and fungus that live on rock surfaces. They slowly break down the rock fabric and aid erosion.

Expansion and contraction due to daily and seasonal heat and cold cause uniform granitic rock to peel off curved layers like an onion (a process called exfoliation).



Most of Lumpy Ridge is 1.4-billion-year-old Silver Plume Granite. The photographic detail shows that the rock solidified from uniform molten magma; mineral grains were faintly aligned by flow.

Rusty rings of iron oxides show the rounding effects of weathering on angular fracture blocks of Silver Plume Granite.



Stop C

Glen Haven (Basement Metamorphic Rocks of the Front Range)

Directions: Continue north on Devils Gulch Road 4.0 miles (passing the turn-off to McGraw Ranch) to the north end of the Estes Park valley. The road drops steeply to the north through several switchbacks leading 2.4 miles down to the town of Glen Haven and the valley of the North Fork of the Big Thompson River. From Glen Haven, continue eastward about 0.6 mile to a sweeping left turn in the road. Stop at the large graveled parking area along the right side of the road beneath towering outcrops of banded black and gray rock.

Stop at this roadside outcrop to examine features of the oldest rocks in this part of the Rocky Mountains. These gray, brown, and black banded rocks are classified as metamorphic rocks (*meta* = change; *morph* = form or shape) because they have been changed by extreme heat and pressure. Take a few minutes to look closely at the outcrops.

These rocks are mixtures of granular, light-colored mineral grains (mostly quartz and feldspar) and flaky, dark-colored mineral grains (mostly biotite and hornblende). The mineral grains are arranged in banded layers that are generally parallel to each other. The layers differ in the proportions of light- and dark-colored minerals, grain sizes, or color. Patterns of layers resemble those of silt and sand deposited by running water (sedimentary deposits). Geologists think the layering in these metamorphic rocks probably started out as sedimentary layering because the chemical compositions of these rocks are similar to compositions of sediments deposited in modern streams and oceans. More conclusively, similar rocks exposed about 15 miles east of here, which were not changed so strongly by metamorphism, show structures and textures that clearly formed during sedimentary deposition.



Fine-scale layering shown by light and dark bands probably originated as sedimentary layering in an ancient ocean basin.
Photograph by Bill Braddock.



Glen Haven

11 Stop C—Glen Haven

Some of the layering has a distinct appearance that geologists know formed by partial melting during intense metamorphism. These distinct layers have a granular, light-colored center of quartz and feldspar bordered by thin margins of biotite and other dark minerals. The minerals that melt at lower temperature (quartz and feldspar) formed the center of the layer, but the dark minerals that only partly melt at higher temperature were displaced outward, forming a concentrated residue along both sides.

The rocks show fluid-looking, wavy convolutions in the layering. The distance between the ridges and furrows of these folds ranges from less than an inch to several feet. If you step back about 10 paces and survey the whole outcrop, you'll see larger folds (tens of feet between the ridges and furrows). Note that most folds "lean to the right" from this vantage point.

Geologists infer from this kind of evidence that most of the folding occurred in a single, long-lasting event. The general shape of the folds indicates that the layering was pushed together and crumpled like a throw rug on a smooth floor. Different parts of the layered package were able to slide past each other at different rates and so they folded a bit differently. Thinly layered parts tend to show small, tight folds, and thicker layers fold with longer wavelengths. You can see the same range of fold sizes in a crashed car: thin body panels crumple, fenders bend and twist, and strong parts of the frame only bend a little.



▲ (Above) Distinctive layering is shown by light-colored seams bordered by thin bands of concentrated dark minerals. Geologists infer that this rock was partially melted, causing the melted (light) minerals and the unmelted (dark) minerals to segregate, at the same time it was folded.

◀ (Left) Wavy patterns of deformed layering show that these rocks folded, crumpled, and sheared under extremely high temperatures and pressures.

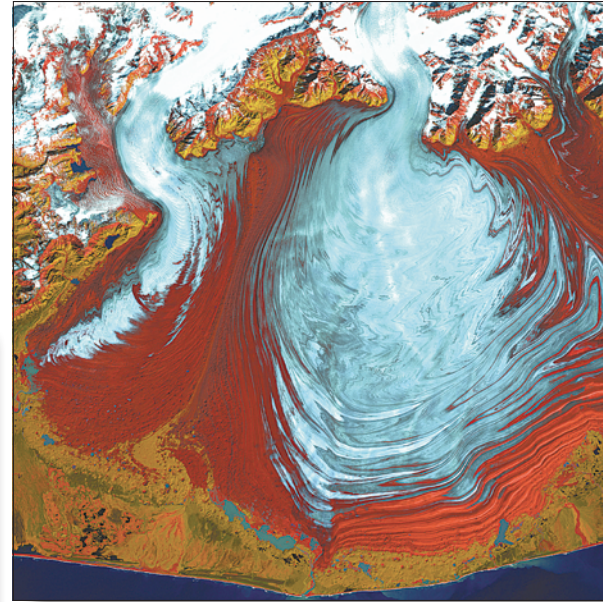
How Do Rocks Fold?

These contorted layers record deformation that must have taken place very slowly over very, very long periods of time. The intense heat and pressure that led to partial melting allowed these rocks to soften and deform, and the entire folding event probably required many millions of years to complete.

The slow process of rock deformation can be compared to the relatively fast deformation observed in a flowing glacier. Glacier ice seems to be hard and inflexible, but, over time scales of years and decades, we can observe glaciers deform and flow.



The shape and size of a fold partly depends on the thickness of the folded layer. Thicker layers generally form broader folds.



Hard glacial ice of the Malaspina glacier in Wrangell-St. Elias National Park, Alaska, flows slowly downward and outward, creating elaborate folds in the stripes of transported moraine. NASA-USGS Landsat 7 image, false-color, August 31, 2000.

How Old Are These Rocks?

The metamorphic rocks that make up the core of the Front Range are the oldest rocks known in the region. Geologists use various laboratory techniques to learn the “absolute” numerical ages of these rocks. These techniques are based on the known rates at which naturally occurring radioactive elements decay. For example, minerals and rocks that contain potassium, rubidium, uranium, or thorium can be analyzed to determine how much of the radioactive element remains in comparison to the amount of radioactive decay product. Analysis of these metamorphic rocks indicates they stopped melting, solidified, and started their radioactive “clocks” about 1.75 billion years ago (that’s about 30 percent as old as the age of the Earth).

13 Stop D—Drake

Stop D Drake (Mountain Valleys)

Directions: Continue eastward along the highway (Devils Gulch Road) beside the North Fork of the Big Thompson River for about 7.2 miles to the town of Drake at the junction with Highway 34, which is also the confluence of the North Fork and the Big Thompson River.

Mountain Valleys

People travel and congregate in mountain valleys for reasons of efficiency and aesthetics. If you want to go west from Drake (6,200 feet altitude) to Estes Park (7,500 feet altitude), you could choose the shortest distance along a straight line, but you would have to climb up and down several ridges at altitudes of more than 8,000 feet along the way. However, if you follow the Big Thompson River, the climb is far gentler—just a steady incline up to Lake Estes—but the route is about 20 percent longer.

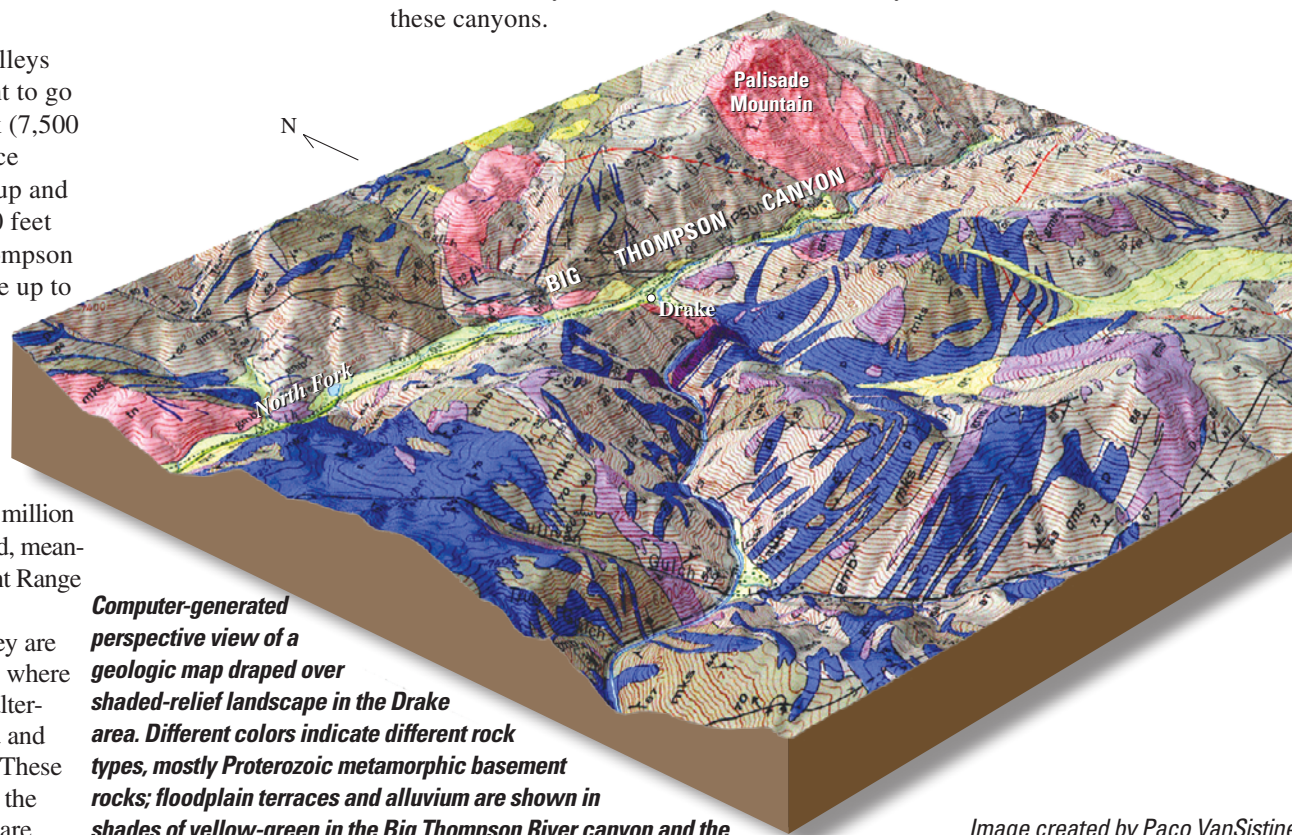
In the Front Range, mountain valleys connect the High Plains (at roughly 5,500 feet altitude) with the upper remnants of an old upland erosion surface (at about 9,000 feet altitude). The rivers and streams carved and eroded the valleys downward from that surface as the mountains were uplifted over the past 15 million years. The numerous deep canyons and their entrenched, meandering routes are evidence of renewed uplift of the Front Range in the last several million years.

Flowing streams follow stable courses where they are hemmed in by rock outcrops on both sides. However, where the valley floor contains much sediment, the stream alternately cuts and fills from side to side by moving sand and gravel that are temporarily stored in terrace deposits. These flat terrace surfaces are attractive building sites along the river—but now and again, we are reminded that they are temporary features subject to change during floods.

Flood Hazard in Mountain Valleys

Water in the Big Thompson River is typically clear because it carries a small load of suspended sediment. As a general rule, most mountain streams don't move much sediment—except during floods. The power of water to move sediment rises quickly as the velocity and discharge (the amount of water passing a fixed point) increase—that's why more sediment gets moved during high flow (flood) conditions. Many things that stand in the floodwater's way may also get moved—large boulders, trees, cars, houses, bridges, and roads.

Mountain rainfall in Colorado is most intense between 7,000 feet and 9,500 feet altitude, because that's typically where rising, cooling air becomes saturated and moisture condenses to rain. By a coincidence of geography, the zone of greatest expected rainfall is at the tops of the deep, narrow canyon stretches of the mountain valleys. Occasional floods will always be a fact of life in these canyons.



Computer-generated perspective view of a geologic map draped over shaded-relief landscape in the Drake area. Different colors indicate different rock types, mostly Proterozoic metamorphic basement rocks; floodplain terraces and alluvium are shown in shades of yellow-green in the Big Thompson River canyon and the canyon of North Fork. One inch equals approximately one mile.

Image created by Paco VanSistine, U.S. Geological Survey.

The Big Thompson Flood

On July 31, 1976, about 7.5 inches of rain fell on the upper Big Thompson River drainage in about an hour in the early evening. The exceptionally heavy rainfall was caused by a very powerful and stationary thunderstorm. All this water moved down the narrow canyon at about 20-25 feet per second (15 miles per hour), scouring the river channel and moving boulders and debris along the channel sides. Many bridges were lost, riverside houses were swept away, and intense erosion took place along all outside bends of the river. The floodwaters caught travelers and residents unaware, and 139 people died in the canyon (five people were reported missing and remain so today).

Official evaluations following the tragic event determined that many deaths in the canyon could have been avoided. Many who died probably could have survived if they had abandoned their vehicles and climbed to safety. It has been many years since clean-up and reconstruction in the canyon, and vegetation has regrown—the geologic effects of the flood are now hard to see. Roadside warning signs (“CLIMB TO SAFETY! IN CASE OF A FLASH FLOOD”) are some of the few visual reminders of this major flood.



Before



After



2004

Ground-level photographs of the same Drake house before and after the flood show numerous large boulders deposited during the 1976 event. Comparative photograph from 2004 shows that flood effects are almost invisible after less than 30 years. Black and white images from U.S. Geological Survey (1979).



July 31, 1976, photograph of large thundercloud over the Big Thompson drainage. Image from U.S. Geological Survey (1979).

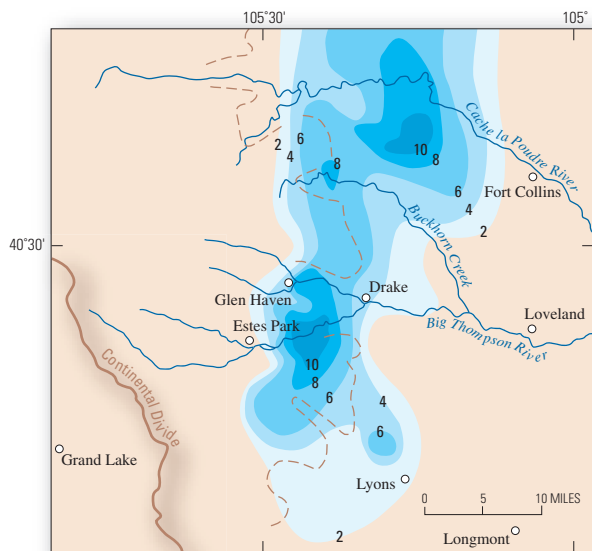
Drake

15 Stop D—Drake

What Is a Hundred-Year Flood?

Simply stated, a hundred-year flood is any flow (discharge) that has one chance in 100 of being exceeded in any given year. It is only a statistical measure, just as the probability that a flipped coin will land heads-up is 1 in 2. If the coin comes up heads five times in a row, the probability that it will be heads again on the sixth try is still 1 in 2. In the same way, a hundred-year flood is just as likely (and just as unlikely) the next year following a flood event as it is 50 years later, 100 years later, or 150 years later.

The Big Thompson flood of 1976 exceeded the 100-year-event probability wherever gaging records were available. The discharge was almost two times greater than the estimated 100-year flow at the canyon mouth, but was even more unusually high (four times greater) in the upper part of the canyon. The flows from this event, although large, were not nearly as great as previous major rainstorms that affected the foothills and eastern plains in 1935 and 1965.



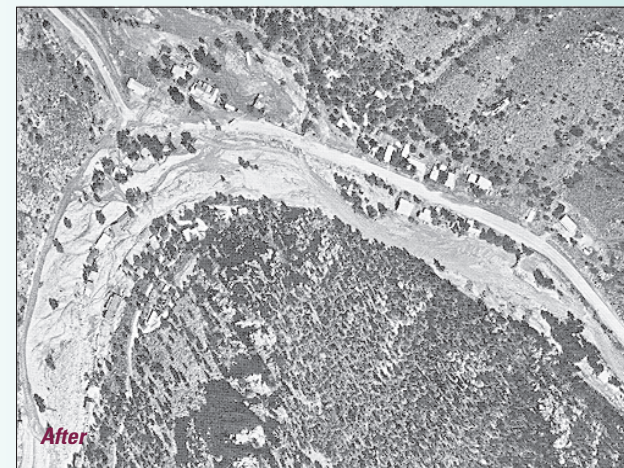
EXPLANATION

- Total rainfall from July 31 to August 1, 1976. Numbers indicate inches of rainfall
- Approximate 8,000 foot elevation contour

Sketch map showing measured and estimated total rainfall for the overnight storm of July 31–August 1, 1976. Highest rainfall amounts occurred near 8,000 feet altitude or lower. Adapted from U.S. Geological Survey (1979).

(Right) Warning signs were installed in most Colorado canyons following the Big Thompson flood. ►

(Below) Aerial photographs taken before and immediately after the flood show the extent of change in the floodplain. Images from U.S. Geological Survey (1979). ▼



Stop E Marys Lake (Colorado–Big Thompson Project)

Directions: From Drake, turn west on Highway 34 toward Estes Park. Proceed about 11 miles to the junction of Highway 34 and Highway 7/36 west of Lake Estes. Turn left and continue south 0.5 mile to signal light. Bear right on Highway 7 and continue south for about 3.4 miles to intersection with Marys Lake Road. Turn right (west) toward Marys Lake and follow the road for 1.0 mile around the lake to the Marys Lake Campground convenience store. Turn left (south) into a gravel parking area next to the lake. A narrative sign board nearby describes the Colorado–Big Thompson Project.

Services and amenities we often take for granted are results of the Colorado–Big Thompson Project (CBT):

Water Supply—Turn on any tap in northern Colorado and cold, clean, fresh water flows. You can rely on this day and night, summer and winter, year after year, regardless of irregular periods of drought and rain.

Food—Go to any grocery and find reliable, affordable supplies of Colorado farm products—corn, wheat, sugar, melons, as well as beef, pork, and poultry that were fattened on local supplies of grain, alfalfa, hay, and sugar-beet pulp.

Power—Turn a switch and tap into electricity generated by falling water—a completely renewable energy source that adds no combustion byproducts to the atmosphere.

Recreation—Enjoy boating, lake fishing, wind-surfing, and other forms of water recreation in numerous reservoirs located in dramatic mountain landscapes.

Flood Control—If you live downstream from one of these dams, sleep soundly night after night with little concern that your house sits in a floodplain.

Landscaping—Enjoy lush gardens and plantings around your home rather than the more austere native vegetation.

Life in the West before 1900

When Major Stephen Long (namesake of Longs Peak) came to this region in 1820 with one of the early U.S. Government surveys of the western territories, he was dismayed by the arid conditions. He declared much of the High Plains to be the “great American desert” and “almost wholly unfit for civilization.”

Many have noted that the 100th meridian (the north–south line of longitude that crosses western Nebraska and Kansas) approximately marks the western boundary of farmland that can support Midwestern crops with natural rainfall (about 22 inches per year). West of the 100th meridian, most of these crops can only grow if irrigated. The early Indians and the Spanish settlers in the Southwest understood these requirements and built ditch-irrigation systems (acequias) along the Rio Grande and elsewhere.

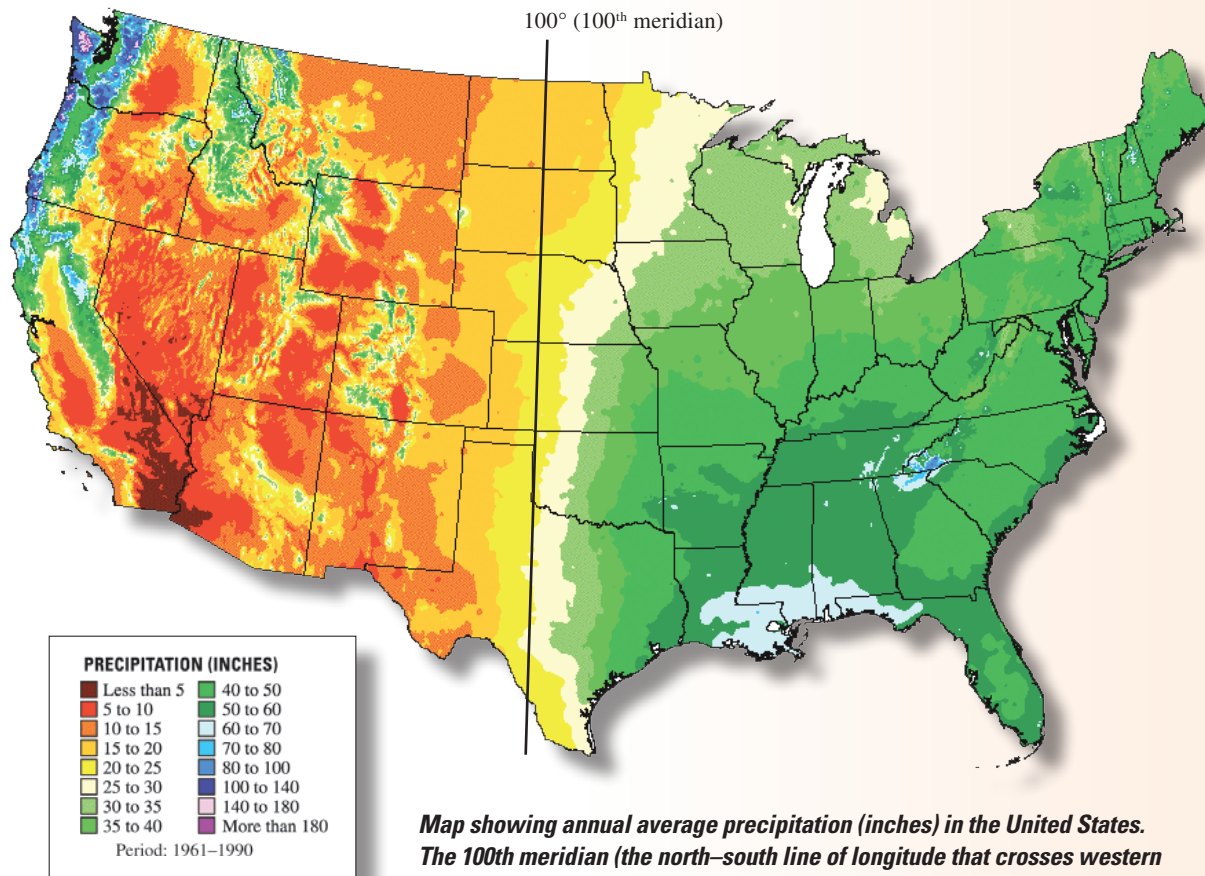
Settlement Brings Change

Following the Civil War, the Federal government was eager to encourage settlement and development of the American West, and it enacted incentives and subsidies to accomplish those goals. New laws allowed settlers and developers to claim title to land and natural resources if they could put them to beneficial use. Such beneficial uses include homesteads for farming, hard-rock mining, timber harvesting, livestock grazing, and use of surface water.

Water’s particular importance in the West was recognized by law in accordance with practices that evolved in the placer-gold fields of California. In the East where rainfall was abundant, water law treated river flow as a shared resource. In the arid West, however, new laws treated surface flow as a commodity (or a tool to aid mining) governed by the rule of prior appropriation. That is, the first party to put surface waters to beneficial use (in mining, agriculture, power generation, etc.) got the first right to use that share of the flow. The doctrine is informally known as “first in time, first in right.”

Marys Lake

17 stop E—Marys Lake



Map showing annual average precipitation (inches) in the United States. The 100th meridian (the north–south line of longitude that crosses western Nebraska and Kansas) generally coincides with the western boundary of farmland that can support Midwestern crops with natural rainfall (about 22 inches per year). Image courtesy of National Oceanic and Atmospheric Administration.

The Reclamation Act of 1902 addressed another major challenge to western water management: most stream flow originates from winter snowpack that melts in the spring. Unless springtime flow can be stored for use when crops need it in the summer growing season, its “beneficial use” for agriculture is lost. Storing the water required large-scale construction projects—for dams, reservoirs, tunnels, and canals—projects too large for a group of farmers to finance. This Act put the Federal government in the business of providing capital and management to major water projects in the West.

The Colorado–Big Thompson Project

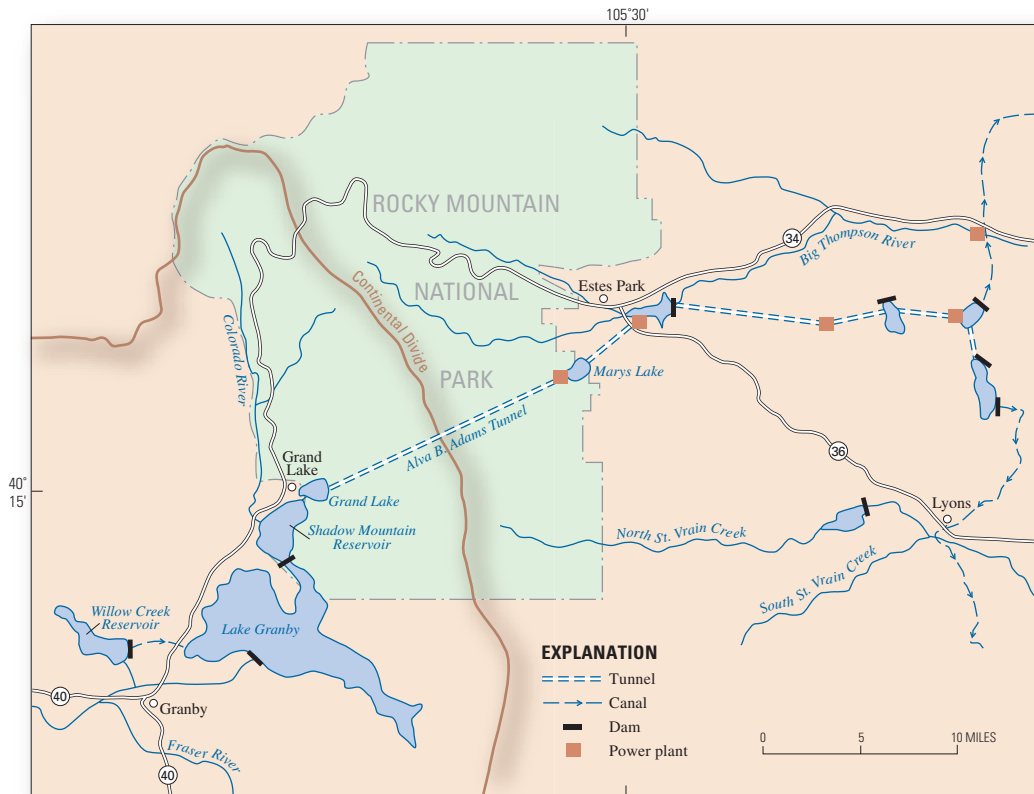
The CBT Project was constructed in stages between 1938 and 1957 to meet numerous needs in northern Colorado. It collects and diverts water from the Colorado River headwaters west of the Continental Divide and transmits it through the 13-mile-long Alva B. Adams tunnel beneath Rocky Mountain National Park to a distribution system along the Big Thompson River drainage on the eastern slope. The need for this trans-mountain water diversion project was anticipated much earlier, and Congress included language in the 1915 Act that established the Park to reserve water rights and allow for project construction adjacent to the Park.

The CBT Project spans 150 miles of waterways and includes 12 reservoirs, 35 miles of tunnels and siphons, and 6 hydroelectric power plants. The project provides municipal water for 30 communities east of the Continental Divide and irrigation water for approximately 615,000 acres along the Big Thompson, Cache la Poudre, and South Platte River drainages.

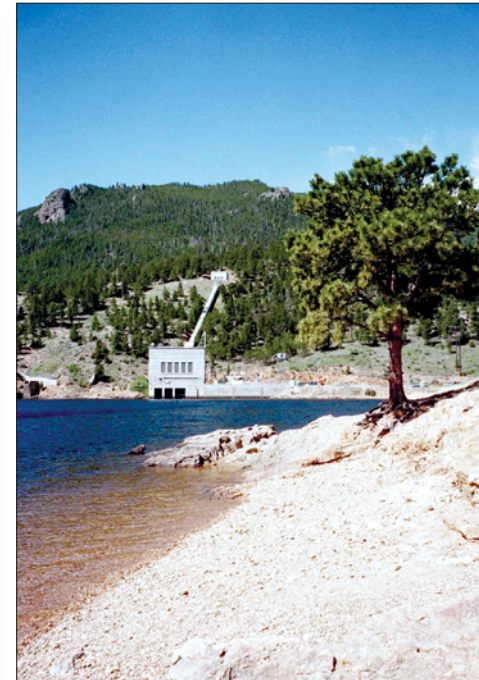
The structure on the far side of Marys Lake is the penstock that carries pressurized water from the Rams Horn tunnel down a 205-foot drop to the Marys Lake power plant. On an annual basis, the average trans-mountain water diversion amounts to 220,000 acre-feet, all of which passes through that penstock structure. That volume is equivalent to the volume of a medium-size automobile emerging from the penstock every second of every day of every month of the year.

Benefits of trans-mountain water diversion are reliable water supply, regulated stream flow through the seasons and climate changes, clean hydroelectric power, recreation, additional lakes and canals, agricultural production, economic development, flood control/mitigation, and increased discharges to the South Platte River system and the Mississippi river drainage.

Trade-offs of trans-mountain water diversion are decreased flow in Colorado River headwaters, decreased discharge to Gulf of California, reduction in wetlands in the upper Colorado River drainage, visual impacts of impoundment structures and power plants and power lines, submergence of land beneath reservoirs, evaporation losses from reservoirs, and reduction in peak flood-flows of dammed rivers.



Schematic map of the main parts of the Colorado–Big Thompson Project showing reservoirs, dams, tunnels, and power plants. Adapted from Northern Colorado Water Conservancy District.



This penstock (conduit) conveys high-pressure water to turbines at the Marys Lake power plant; five additional hydroelectric plants generate renewable energy for the project.

Marys Lake

19 Stop F—Moraine Park

Stop F

Moraine Park Museum (Glaciers, Climate Change, and Early Man)

Directions: Continue northwest on Marys Lake Drive about 1.6 miles to “T” junction with Highway 36. Drive about 2.5 miles west on Highway 36 past the Beaver Meadows Visitor Center and through Rocky Mountain National Park entrance station. Proceed about 0.2 mile west to junction with Bear Lake road. Turn left (south) toward Bear Lake and proceed about 1.3 miles to Moraine Park Museum.

Glacial Features of Rocky Mountain National Park

As you start your drive along Bear Lake road, you will cross a small creek that flows between two boulder-strewn forested ridges. The ridge on the left is a remnant of the lateral glacial moraine of the older glacial advance in the Park, known as the Bull Lake glaciation (about 160,000 to 120,000 years ago). The higher ridge on the right is the north lateral moraine of the younger major glacial advance, known as the Pinedale glaciation (about 18,000 to 12,000 years ago).

The view south and west from the Moraine Park Museum parking lot across the meandering Big Thompson River shows many of the major landforms that were produced by the valley glaciers of the Ice Age during the last 2 million years. The densely forested ridge on the far (south) side of Moraine Park is the south lateral moraine of the Pinedale glaciation, the southern twin of the moraine you drove across on the way here. The moraines show no sign of stratification and contain all kinds and sizes of rock because they are deposits of loose rubble that were shoved downhill and laterally outward by the flowing river of ice.

As you look west up the valley of the Big Thompson River, note that the forested canyon has steep walls and a wide, flat bottom—the classic U-shaped profile of glacial valleys. The valley shape shows that these valley glaciers were more efficient at plucking and removing loose rock from the valley sides than they were at scraping the valley bottoms. Geologists estimate that these glaciers were generally 500 feet to locally about 1,000 feet thick during the major glacial advances, based on the heights of the moraines and other features.

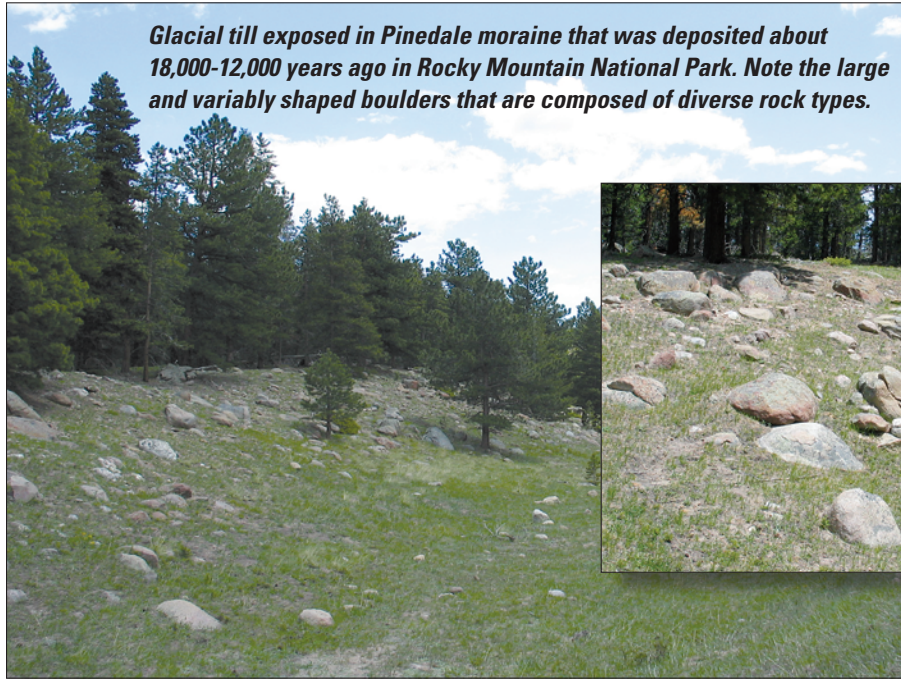


◀ (Left) View across the former lake basin of Moraine Park, which filled with glacial outwash sediment as the last major valley glacier receded about 10,000 years ago. Gently inclined forested ridge on the far side of Moraine Park is the south lateral moraine; its height gives an indication of the thickness of the ice lobe.

(Below) View from Many Parks Curve on Trail Ridge Road toward the southeast, showing Moraine Park and prominent lateral moraines formed by the younger glacial advance of the Pinedale glaciation (about 18,000 to 12,000 years ago). ▼

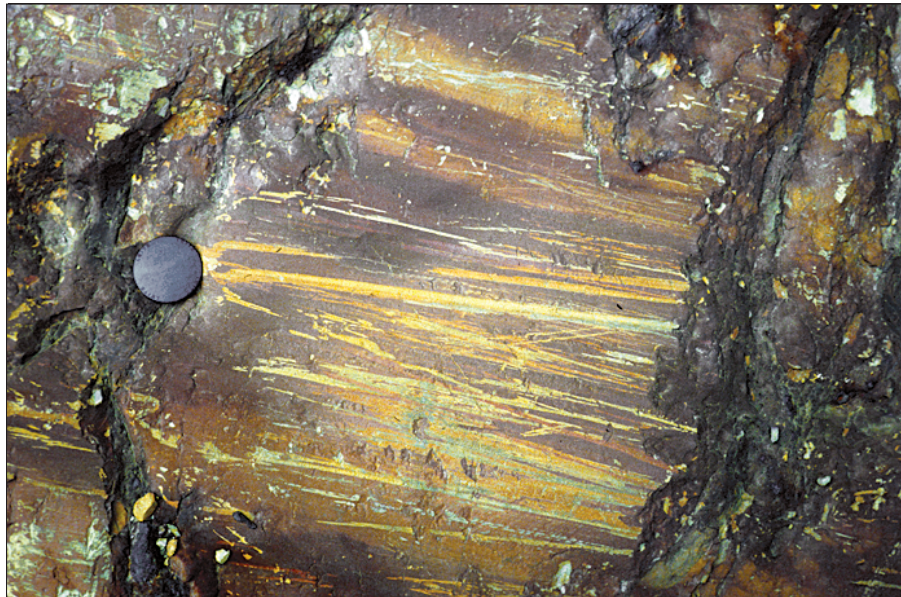


Glacial till exposed in Pinedale moraine that was deposited about 18,000-12,000 years ago in Rocky Mountain National Park. Note the large and variably shaped boulders that are composed of diverse rock types.



(Below Left) The forces exerted by passing glaciers leave telltale signs in the rocks. Striated grooves and shiny polish are created by friction between rocks beneath the glacier and rocks carried in the glacial ice. Image from Glacier National Park, courtesy of Paul Carrara.

(Below Right) Forest Canyon upstream from Moraine Park shows the characteristic “U-shape” of glacial valleys. This profile reflects efficient removal of all loose valley-side material by the glacier, as well as some excavation beneath the glacier.



21 Stop F—Moraine Park

Climate and the Ice Age

The climate on Earth is constantly changing in response to complex interactions of the amount of energy generated by the Sun, sunspot activity, tilt of the Earth's axis and how it revolves around the Sun, atmospheric conditions on Earth, ocean circulation patterns, and other lesser factors.

Scientists can document changes in climate over time through various kinds of records. The width of tree growth-rings reflects the amount of precipitation in the spring and summer months, and investigators have examined these records that cover the last several thousand years. The ratios of carbon isotopes and oxygen isotopes fluctuate systematically depending on average temperatures, and patterns of temperature change have been documented by isotope records for millions of years in the past. A typical record shows that world-wide climate started cooling about 5 million years ago, and then got significantly cooler about 2 million years ago at the start of the Ice Age. Evidence throughout the Rocky Mountain region indicates glacial advances occurred at about 18, 50, 73, 125, 198, and 600 thousand years ago, although only a couple of these events left a lasting record of glacial moraine deposits. Many of the older deposits were mostly erased by the younger glacier advances.

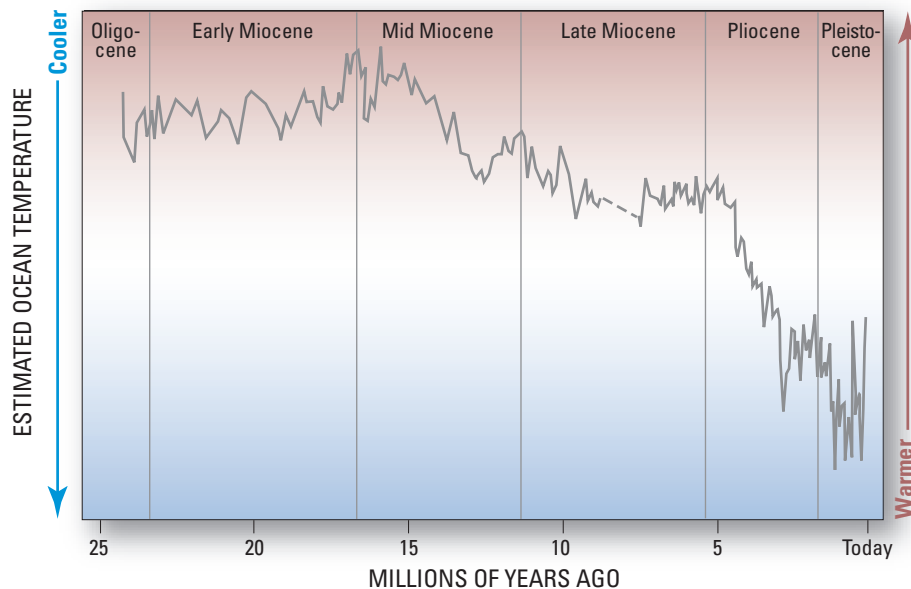


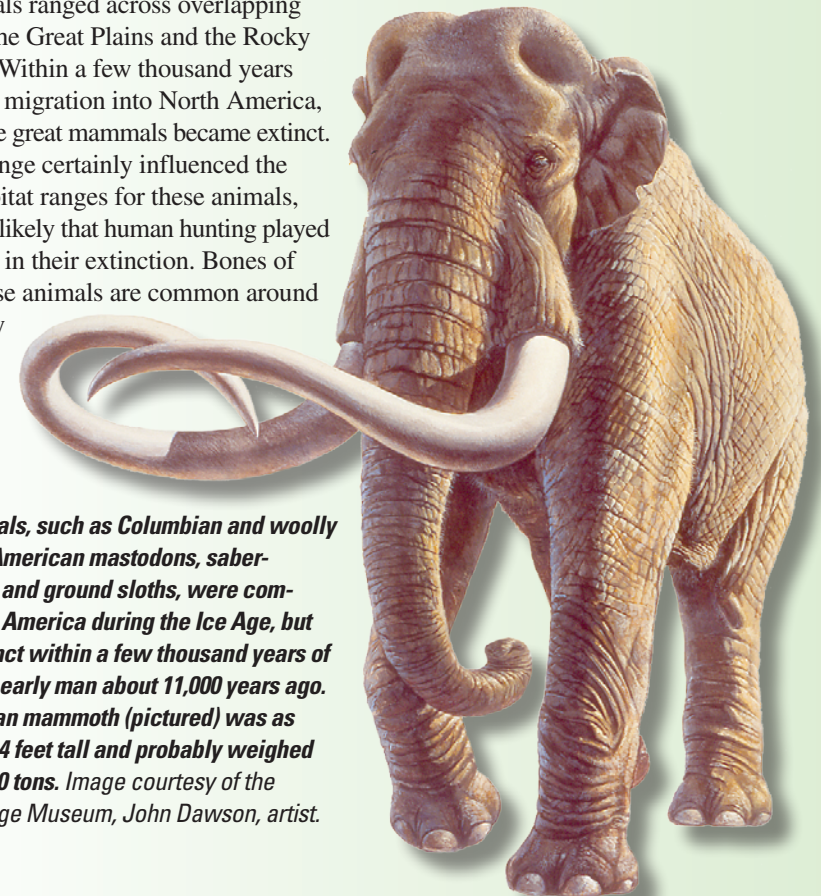
Diagram showing long-term changes in ocean temperature caused by natural climate change. The diagram is based on variations in isotopic composition of certain fossil sea shells that record sea-water temperature. Based on several sources in Hsu (1986).

What Was It Like During the Ice Age?

The most recent Pinedale glaciation was ending at about the time the first humans were making their way into North America after about 11,000 years ago. Here in Moraine Park, these people probably would have found a shallow lake covering the floor of the valley. The lake was formed behind the horseshoe-shaped terminal moraine that temporarily dammed the Big Thompson River at the eastern end of Moraine Park.

The glacial ice had pushed all the way down to about 8,000 feet altitude. By comparison, today's permanent ice fields in Rocky Mountain National Park are all higher than about 11,000 feet altitude. As the climate warmed and the glaciers receded, meltwaters carried sand and silt into the lake behind the moraine dam and eventually filled it to form a flat boggy meadow, much like what you see today in Moraine Park.

Fossils tell us that large mammals were commonplace at the end of the Ice Age, including woolly mammoths, Columbian mammoths, American mastodons, saber-toothed cats, caribou, long-horned bison, peccaries (related to pigs), and ground sloths. These animals ranged across overlapping habitats of the Great Plains and the Rocky Mountains. Within a few thousand years after human migration into North America, most of these great mammals became extinct. Climate change certainly influenced the Ice-Age habitat ranges for these animals, but it is also likely that human hunting played a major role in their extinction. Bones of some of these animals are common around sites of early human habitation.



Large mammals, such as Columbian and woolly mammoths, American mastodons, saber-toothed cats, and ground sloths, were common in North America during the Ice Age, but became extinct within a few thousand years of the arrival of early man about 11,000 years ago. The Columbian mammoth (pictured) was as much as 13-14 feet tall and probably weighed as much as 10 tons. Image courtesy of the George C. Page Museum, John Dawson, artist.

Suggested Additional Reading

- Braddock, W.A., and Cole, J.C., 1990, Geologic map of Rocky Mountain National Park and vicinity, Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-1973.
- Eaton, G.P., 1986, A tectonic redefinition of the Southern Rocky Mountains: Tectonophysics, v. 132, p. 163-193.
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- Mills, Enos A. [numerous books and articles; most titles have been reprinted by various publishers; several are especially pertinent to the Estes Park area], Spell of the Rockies (1911), Rocky Mountain Wonderland (1915), and Romance of Geology (1919).
- Raup, O.B., 1996, Geology along Trail Ridge Road—a self-guided tour for motorists: Falcon Press, Rocky Mountain Nature Association, 74 p.
- Shelton, J.S., 1966, Geology Illustrated: W.H. Freeman and Company, 434 p.
- U.S. Geological Survey, 1979, Storm and flood of July 31–August 1, 1976, in the Big Thompson River and Cache la Poudre River basins, Larimer and Weld Counties, Colorado: U.S. Geological Survey Professional Paper 1115, 152 p.
- U.S. Geological Survey, 1987, Rocky Mountain National Park, Colorado, with a section on Rocky Mountain National Park: The story of its origin, by Glen Kaye: U.S. Geological Survey 1:50,000-scale topographic map.
- Wilkinson, C.F., 1992, Crossing the next meridian—Land, water, and the future of the west: Island Press, 376 p.

Web Sites of Interest

- www.estesnet.com City of Estes Park web site; government and tourist information.
- www.ncwcd.org Northern Colorado Water Conservancy District, operators of the Colorado–Big Thompson Project.
- www.nps.gov/romo/ The official National Park Service web site for Rocky Mountain National Park.
- www.rmna.org Rocky Mountain Nature Association supports education, preservation, and research objectives of Rocky Mountain National Park, and is a source for books, educational items, and maps for the region.



About the Author

James C. Cole has worked for the U.S. Geological Survey since 1976 and has conducted research in many regions of the West, as well as in the Kingdom of Saudi Arabia. He earned a Ph.D. in Geology at the University of Colorado for studies of the complex basement rocks of this part of the Front Range, under the guidance of Professor Bill Braddock. Together, they produced the geologic map of Rocky Mountain National Park.

*Silent stories set in stone,
Yet ready to be read.*

*Tales tell of gravity's unyielding pull,
And time's relentless arrow
Driving rock to dust to mud,
And then to rock again.*

*Earth speaks to all who look with open mind
And seek to find the reasons why.*

~ the author

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